Final Report:

Concentrations of Selenium and Mercury in Common Goldeneyes from the Great Salt Lake, Utah

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Abstract

We examined selenium and mercury concentrations in male common goldeneyes (*Bucephala clangula*) that spent the winter of 2005–2006 on the Great Salt Lake, Utah. Selenium concentrations in livers were 15.3 ± 1.2 µg/g (mean ± SE on a dry-weight basis) and 16.7 ± 1.2 µg/g in blood. Mercury concentrations were 38.8 ± 4.5 µg/g in livers and 14.3 ± 1.2 µg/g in blood. Selenium concentrations in liver, selenium concentrations in blood, mercury concentrations in liver, and mercury concentrations in blood were all highly correlated with each other. Body mass and liver mass were not correlated with the concentration of selenium or mercury concentration in either blood or liver. Fat mass was negatively correlated with liver concentrations of selenium and mercury and with blood concentrations of mercury, but not blood concentrations of selenium. Selenium and mercury concentrations increased across time in ducks collected around Fremont Island but not in ducks collected around Stansbury Island.

Introduction

Selenium is a naturally occurring trace element, and small quantities of it are essential for animal health. However, it becomes toxic at higher concentrations. Elevated concentrations of selenium can cause reduced egg hatchability, embryonic defects, and lower survival rates of chicks and adults (Ohlendorf et al.1989, Ohlendorf 2003). For example, birds foraging in California's Kesterson Reservoir, which was the disposal site for subsurface agricultural drainage from portions of the western San Joaquin Valley, accumulated high concentrations of selenium in their tissues (Ohlendorf 2002, 2003). The high concentrations of selenium impaired the reproductive ability of several avian species nesting at Kesterson Reservoir and caused mortality of adult birds (Ohlendorf et al. 1989; Ohlendorf 2002, 2003).

The Great Salt Lake (GSL) is the fourth-largest terminal lake in the world and is an important region for breeding and migratory waterbirds including common goldeneyes (*Bucephala clangula*) that overwinter on it (Aldrich and Paul 2002). Because GSL is a closed basin, contaminants (e.g., mercury and selenium) may accumulate in the GSL. Thus, GSL ducks are likely exposed to these contaminants, and elevated contaminant concentrations may adversely affect their survival and reproduction (reviewed in Takekawa et al. 2002). Indeed, mercury concentrations identified in a 2005 reconnaissance investigation on the GSL were the highest among published results for common goldeneye (Gerstenberger et al. 2004). Hence, there is a need to ensure that selenium concentrations in the GSL do not reach levels that would impair the health or reproduction of the birds that depend upon the GSL. For this reason, the Utah Division of Water Quality wants to establish a water standard for selenium in the GSL. To aid this effort, we measured selenium and mercury concentrations in common goldeneyes soon after they arrived on the GSL and then again in February and March before they migrate from the GSL. Although the continental population of common goldeneye is relatively stable compared to other North American sea duck populations (e.g., eiders and scoters), insight into mercury and selenium concentrations in common goldeneye wintering on GSL presents a potentially unique opportunity to understand relationships between selenium and mercury concentrations in ducks and how their concentrations affect the condition of wintering sea ducks.

This study was designed to answer the following specific questions.

1. What are selenium and mercury concentrations in the blood and liver of male common goldeneye that winter on the GSL?
2. Do goldeneyes accumulate selenium and mercury while on the GSL?
3. Do selenium and mercury concentrations vary based on the age of the birds?
4. Are selenium and mercury concentrations in blood and liver correlated?
5. Do selenium or mercury concentrations affect body condition of goldeneyes?

Methods

Collection of goldeneyes. From November 2005 through March 2006, we used a shotgun to collect 40 male goldeneyes located on the GSL (Appendix 1). We collected ducks from two parts of the Great Salt Lake. One part was around Fremont Island in the northeastern section of the Great Salt Lake (Fremont Island and Farmington Bay); these ducks will be referred to as Fremont Island ducks. The other collection area was around Stansbury Island, Gilbert Bay, and the southern side of Carrington Bay; these ducks will be called the Stansbury Island ducks.

We used a syringe to collect at least 1 mL of blood from the thoracic cavity. Liver and blood samples were placed in separate Whirl-Pak® bags and frozen. We weighed and measured the birds, and determined their age by plumage. We also removed and weighed abdominal and intestinal fat.

Selenium and mercury analysis. Blood and liver samples from all ducks were sent to Laboratory and Environmental Testing Incorporated (LET), Columbia, Missouri, for selenium and mercury analyses. LET analyzed the tissue for total selenium using hydride generation atomic absorption spectrometry and mercury using the cold vapor atomic absorption spectrometry, with a target reporting limit of 0.2 µg/g. Quality control of chemical analyses was conducted using one or more method blanks, matrix spikes, matrix spike duplicates, and reference samples for each sample batch (CH2M HILL 2006).

Statistical analyses. Data on selenium and mercury concentrations were normally distributed based on the D'Agostino-Pearson Omnibus K^2 normality test. Hence, parametric statistics were used. Analyses of Variance (ANOVAs) were used to determine the effect of collection site (Fremont Island versus Stansbury Island), and age of birds (juveniles versus adults) on selenium and mercury concentrations in blood and liver. Correlation analyses were conducted to compare selenium and mercury concentration in an individual duck's blood and liver. Selenium and mercury concentrations also were tested for correlation with body mass, liver mass, and fat mass. In all tests, results were considered significant if $P < 0.05$.

To assess the effect of collection date, we changed all collection dates to an Ordinal day with day 1 being November 29, 2005: the first day that a duck was collected. March 16, 2006, which was the last day a duck was collected, was changed to day 114. We then conducted a regression analysis to compare the different dependent variables to the Ordinal day. Data for collection date and site were confounded because almost all Fremont Island ducks were collected prior to February 1, 2006 and Stansbury Island ducks were collected after that date. Hence, we analyzed Fremont Island and Stansbury Island ducks separately.

Results

Selenium and mercury analyses.– Mean ($\pm$ SE) selenium concentrations in livers were 15.3 $\pm$ 1.2 µg/g on a dry-weight basis and 16.7 $\pm$ 1.2 µg/g in blood. Mercury concentrations were 38.8 $\pm$ 4.5 µg/g in livers and 14.3 $\pm$ 1.2 µg/g in blood (Table 1). Selenium and mercury concentrations in both livers and blood did not vary by age but collection site (Fremont Island versus Stansbury Island) (or associated sampling date) affected selenium concentrations in liver and mercury concentrations in both liver and blood (Table 2).

Selenium concentrations in liver, selenium concentrations in blood, mercury concentrations in liver, and mercury concentrations in blood were all highly correlated with each other (Table 3). Body mass and liver mass were not correlated with concentrations of selenium or mercury in either blood or liver (Table 3). Fat mass was negatively correlated with selenium concentrations in liver, mercury concentrations in liver, and mercury concentrations in blood.

Among Fremont Island ducks, selenium and mercury concentrations in both liver and blood samples varied by collection day but this was not true for Stansbury Island ducks (Table 4, Figure 1-4). Body mass, liver mass, and fat mass did not vary by collection day for either Fremont Island or Stansbury Island ducks (Table 4).

Discussion

In male common goldeneyes, we found that selenium concentrations in livers ranged from 4 to 48 µg/g. In earlier studies on birds collected from GSL (Conover et al. 2007*a, b*), we found that selenium concentrations in livers ranged from 5 to 28 µg/g in eared grebes (*Podiceps nigricollis*) and 4 to 14 µg/g in California gulls (*Larus californicus*). Mean selenium concentration in livers was higher in goldeneyes (mean =15.3 µg/g) than in eared grebes (mean = 12.0 µg/g) or California gulls (mean = 8.1 µg/g). In other avian species collected elsewhere, mean background levels of selenium have been reported to be less than 10 µg/g in livers (USDI 1998, Ohlendorf 2003).

Mean selenium concentration in blood samples from our goldeneyes was 16.7 µg/g (range =1 to 34). In California gulls that we collected on the GSL, mean selenium concentration in blood was 18.1 µg/g (range = 5 to 46) and in eared grebes 20.9 µg/g (range= 1 to 55; Conover et al. 2007*a*,*b*). Selenium concentrations in the blood of American kestrels (*Falco sparverius*), red-tailed hawk (*Buteo jamaicensis*), northern harrier (*Circus cyaneus*), barn owl (*Tyto alba*), and loggerhead shrike (*Lanius ludovicianus*) from a contaminated grassland in California ranged from 1 to 38 µg/g dry weight (Santolo and Yamamoto 1999). Selenium concentrations in whole blood above 2 µg/g are considered to exceed normal background, and 5 µg/g is considered a provisional threshold indicating that further study is warranted (USDI 1998).

In GSL goldeneyes, we found that selenium levels in liver and blood samples were both highly correlated with mercury concentrations in liver and blood. Among California gulls, selenium concentrations in blood were correlated with mercury concentrations in blood but not in livers (Conover et al. 2007*a*). Among male eared grebes, selenium concentrations in both blood and liver tissues were correlated with mercury levels in blood but not in livers (Conover et al. 2007*b*). Among female eared grebes, selenium and mercury concentrations were not related (Conover et al. 2007*b*). In wading birds, selenium and mercury concentrations were positively correlated in the blood, but not in liver tissues (Goede and Wolterbeek 1994). In surf scoters (*Melanitta perspicillata*) collected from San Francisco Bay, California, selenium and mercury concentrations were not correlated (Ohlendorf et al. 1991).

One reason that selenium and mercury concentrations in birds are correlated is because selenium and mercury can interact to form a stable, complex so that selenium may provide birds some protection from mercury toxicity (Ohlendorf 2003, Wiener et al. 2003). This interaction between mercury and selenium may cause an enhanced accumulation and retention of both chemicals in birds (Furness and Rainbow 1990, Scheuhammer et al. 1998, Spalding et al. 2000, Henny et al. 2002). Differences in blood and liver concentrations of selenium may result from initial faster selenium elimination in liver than blood and to the binding of selenium to inorganic mercury creating an inert mercury-selenium protein (Wayland et al. 2001).

In eared grebes and California gulls collected from the GSL, we found that age, collection day, and collection site affected selenium concentrations in their blood and liver. In this study, we found that age did not affect selenium or mercury concentrations in male goldeneyes from the GSL but collection day affected selenium and mercury concentrations for Fremont Island ducks but not Stansbury Island ducks. We are unable to assess the impact of collection site on selenium and mercury concentrations because collection day was confounded by collection site (most Fremont Island ducks were collected prior to February 1 and most Stansbury Island ducks were collected after that date). However, it is likely that collection site did not have a significant effect on selenium concentrations in goldeneyes because these ducks were very mobile while on GSL and foraged over wide areas, including in freshwater marshes (J. Vest, unpublished). In contrast, eared grebes are not very mobile while on the GSL because they cannot fly. Likewise, California gulls on the GSL cannot venture far from the nest to forage during the breeding season.

High selenium concentrations can affect the health of mature birds. At Kesterson Reservoir, chronic selenium toxicosis caused American coots (*Fulica americana*) to lose mass and feathers (Ohlendorf et al. 1990). American kestrels (*Falco sparverius*) fed a diet containing 12 µg Se/g of food had a lower ratio of fat and a higher ratio of lean mass to total body mass (Yamamoto and Santolo 2000). Adult mallards (*Anas platyrhynchos*) maintained on a diet enriched with 20 µg Se/g of food had lesions in their liver and integument. Mallards on a diet of 40 µg/g lost weight and exhibited abnormalities such as feather loss, loss of nails, and beak necrosis (Albers et al. 1996, O'Toole and Raisbeck 1998). We noted no abnormalities among the goldeneyes that we collected from the GSL. In our goldeneyes, body and liver mass were not correlated with either selenium or mercury concentrations. However, fat mass was negatively correlated with liver concentrations of both selenium and mercury and mercury concentrations in blood. These findings raise the possibility that high levels of these contaminants may reduce the ability of male goldeneyes that are over-wintering on GSL to accumulate or retain fat.

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Table 1. Effect of collection site, collection date, and duck age on the mean (± SE) concentration of selenium (ug/g dry weight), concentration of mercury (ug/g dry weight), and avian mass (g wet weight) of male goldeneyes collected from around Fremont Island and Stansbury Island on the Great Salt Lake, Utah from November 2005 through January 2006 (early season) and from February 2006 through March 2006 (late season).

	All birds	Collection sites		Collection dates		Age	
		Fremont	Stansbury	Early	Late	Juvenile	Adult
N =	40	20	20	21	19	17	23
Se – liver	15.3 ± 1.2	12.6 ± 1.5	18.0 ± 1.7	12.2 ± 1.4	18.7 ± 1.7	12.7 ± 1.6	17.2 ± 1.6
Se—blood	16.7± 1.2	16.3± 1.9	17.1 ± 1.7	15.9 ± 1.8	17.6 ± 1.7	14.8 ± 1.5	18.1± 1.8
Hg—liver	38.8 ± 4.5	23.5 ± 3.7	54.1 ± 6.7	22.3 ± 3.6	56.4 ± 6.6	31.3 ± 6.5	44.3 ± 6.0
Hg—blood	14.3 ± 1.2	10.5 ± 1.1	18.1 ± 1.8	10.4 ± 1.0	14.1 ± 2.4	13. 4 ± 1.8	15.0 ± 1.6
Mass—body	1086 ± 14	1114 ± 20	1057 ± 16	1117± 19	1050 ± 16	1048 ± 20	1113 ± 16
Mass—liver	32.1 ± 1.0	33.9 ± 1.6	30.4 ± 1.3	34 ± 1.5	30.1 ± 1.3	33.2 ± 1.5	31.3 ± 1.4
Mass—fat	10.5 ± 1.0	12.5 ± 1.3	8.6 ± 1.3	12.8 ± 1.3	8.0 ± 1.2	10.7 ± 1.6	10.4 ± 1.2

Table 2. Results of ANOVA tests examining the effect of collection site (around Fremont Island versus Stansbury Island) and age of bird (juveniles versus adults) on concentrations of selenium and mercury in male goldeneyes collected on the Great Salt Lake during the winter of 2005–2006 (d.f. = 1,32 for all tests).

Term	Selenium (liver)		Selenium (blood)		Mercury (liver)		Mercury (blood)	
	F	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Site	5.25	0.03	0.04	0.84	14.39	0.001	13.10	0.001
Age	1.61	0.21	1.38	0.25	0.37	0.55	0.06	0.81
Site X Age	2.67	0.11	1.16	0.29	0.94	0.34	1.09	0.30

Table 3. Regression analyses between selenium concentrations in the blood and liver, mercury concentrations in the blood and avian mass using all male goldeneyes (juveniles and adults) collected from November 2005 through March 2006 on the Great Salt Lake, Utah (*d.f.* = 1,38 for all tests).

Variable 1	Variable 2	r^2	*F*	*P*
Se (liver)	**Body mass**	**0.01**	**0.27**	**0.61**
	Liver mass	**0.09**	**3.79**	**0.06**
	Fat mass	**0.12**	**5.23**	**0.03**
	Se (liver)	**--**	**--**	**-**
	Se (blood)	**0.57**	**51.04**	**<0.001**
	Hg (liver)	**0.81**	**162.43**	**<0.001**
	Hg (blood)	**0.59**	**55.48**	**<0.001**
Se (blood)	**Body mass**	**0.01**	**0.25**	**0.62**
	Liver mass	**0.01**	**0.35**	**0.56**
	Fat mass	**0.01**	**0.22**	**0.64**
	Se (liver)	**see above**		
	Se (blood)	**--**	**--**	**--**
	Hg (liver)	**0.28**	**15.08**	**<0.001**
	Hg (blood)	**0.33**	**19.15**	**<0.001**
Hg (liver)	**Body mass**	**0.04**	**1.67**	**0.20**
	Liver mass	**0.09**	**3.73**	**0.06**
	Fat mass	**0.15**	**6.85**	**0.01**
	Se (liver)	**see above**		
	Se (blood)	**see above**		
	Hg (liver)	**--**	**--**	**--**

	Hg (blood)	0.74	108.74	<0.001
Hg (blood)	Body mass	0.04	1.68	0.20
	Liver mass	0.01	0.07	0.80
	Fat mass	0.17	7.59	0.01
	Se (liver)	see above		
	Se (blood)	see above		
	Hg (liver)	see above		
	Hg (blood)	__	__	__

Table 4. Regression analyses between collection date (converted to an Ordinal day) and selenium concentrations in the blood and liver, mercury concentrations in the blood and avian mass using male goldeneyes collected around Fremont Island from December 7, 2005 through January 17, 2006 and around Stansbury Island from December 7, 2005 through March 22, 2006 on the Great Salt Lake, Utah (*d.f.* = 1,18 for all tests).

Location	Dependent variable	r^2	F	P
Fremont Island				
	Body mass	**0.00**	**0.00**	**0.95**
	Liver mass	**0.04**	**0.74**	**0.40**
	Fat mass	**0.05**	**1.00**	**0.33**
	Se (liver)	**0.53**	**20.58**	**<0.001**
	Se (blood)	**0.34**	**9.26**	**0.007**
	Hg (liver)	**0.65**	**33.58**	**<0.001**
	Hg (blood)	**0.66**	**34.34**	**<0.001**
Stansbury Island				
	Body mass	**0.06**	**1.27**	**0.28**
	Liver mass	**0.09**	**1.73**	**0.20**
	Fat mass	**0.12**	**2.49**	**0.13**
	Se (liver)	**0.09**	**1.81**	**0.20**
	Se (blood)	**0.01**	**0.11**	**0.75**
	Hg (liver)	**0.13**	**2.70**	**0.12**
	Hg (blood)	**0.08**	**1.49**	**0.23**

Figure 1. Effect of collection date (Ordinal day 1 is November 29, 2005 while day 50 is January 17, 2006) on selenium concentrations (ug/g dry weight) in livers of male goldeneyes collected around Fremont Island, Great Salt Lake, Utah.

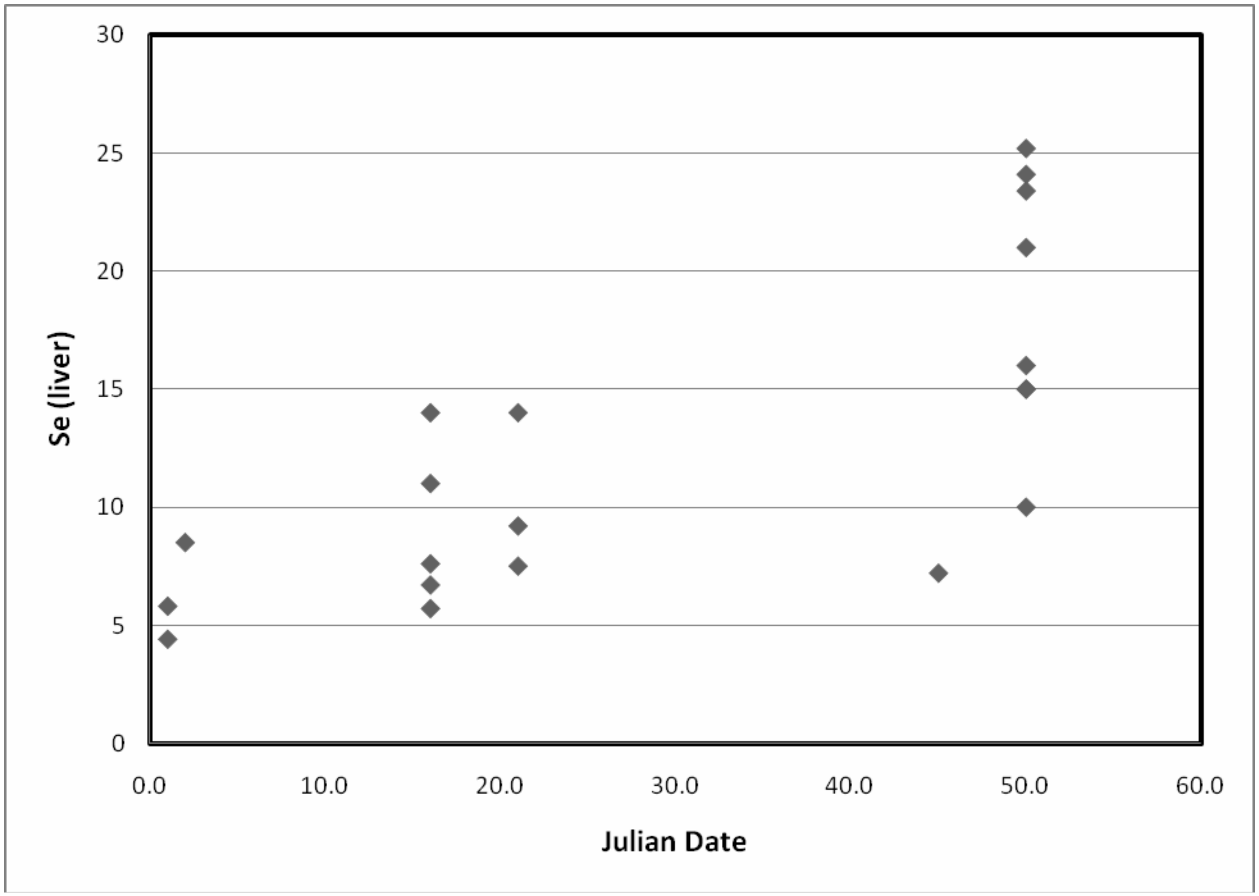


Figure 2. Effect of collection date (Ordinal day 1 is November 29, 2005 while day 50 is January 17, 2006) on selenium concentrations (ug/g dry weight) in blood of male goldeneyes collected around Fremont Island, Great Salt Lake, Utah.

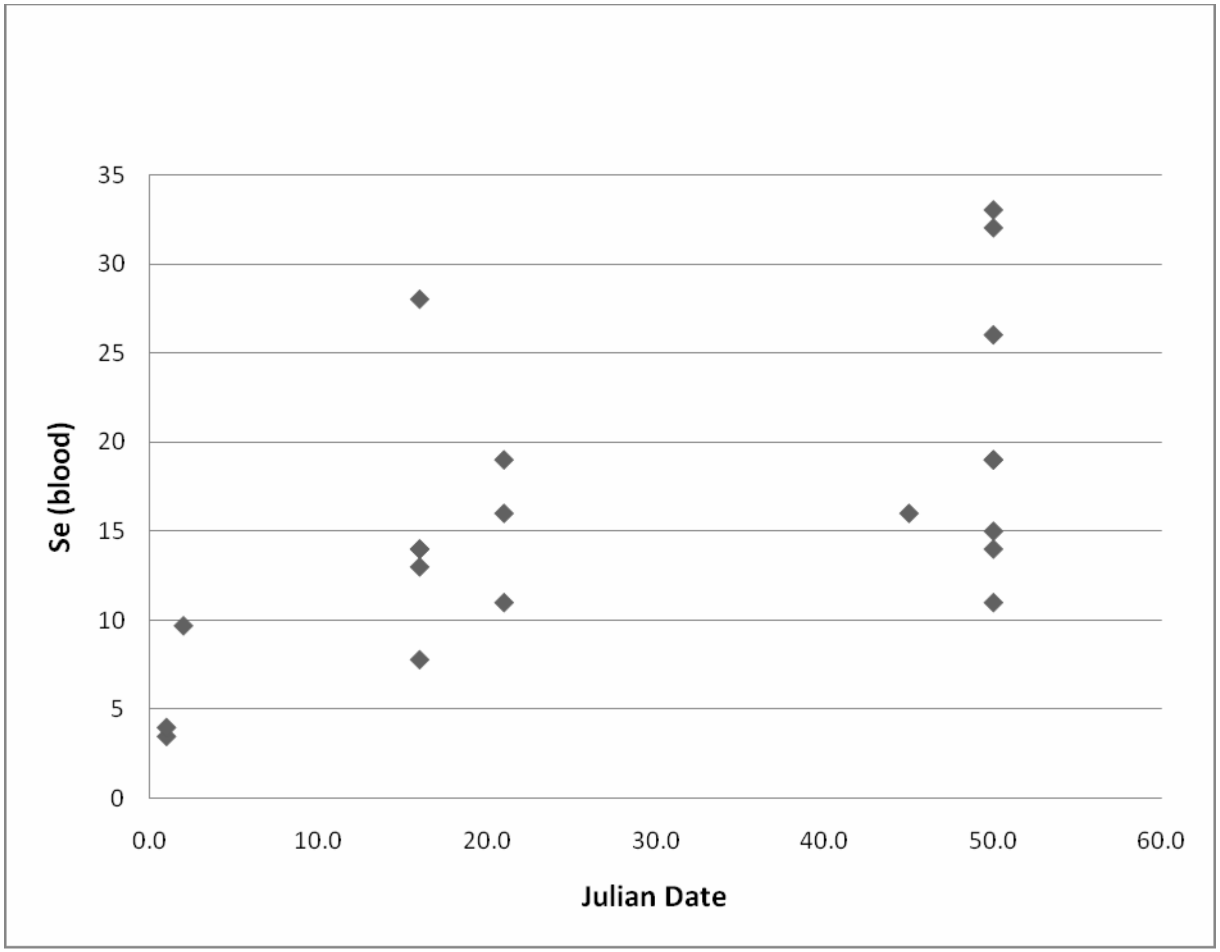


Figure 3. Effect of collection day (Ordinal day 1 is November 29, 2005 while day 50 is January 17, 2006) on mercury concentrations (ug/g dry weight) in livers of male goldeneyes collected around Fremont Island, Great Salt Lake, Utah.

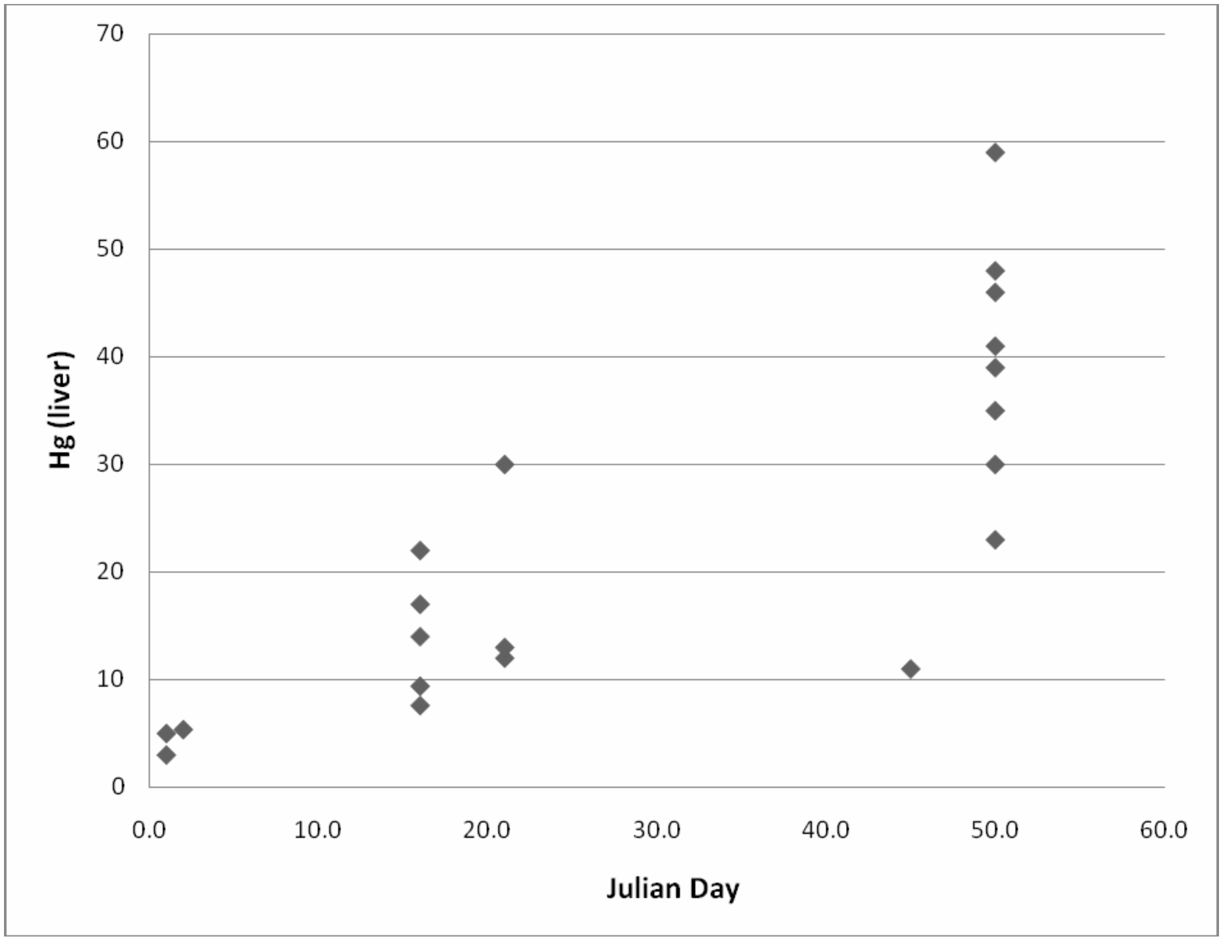
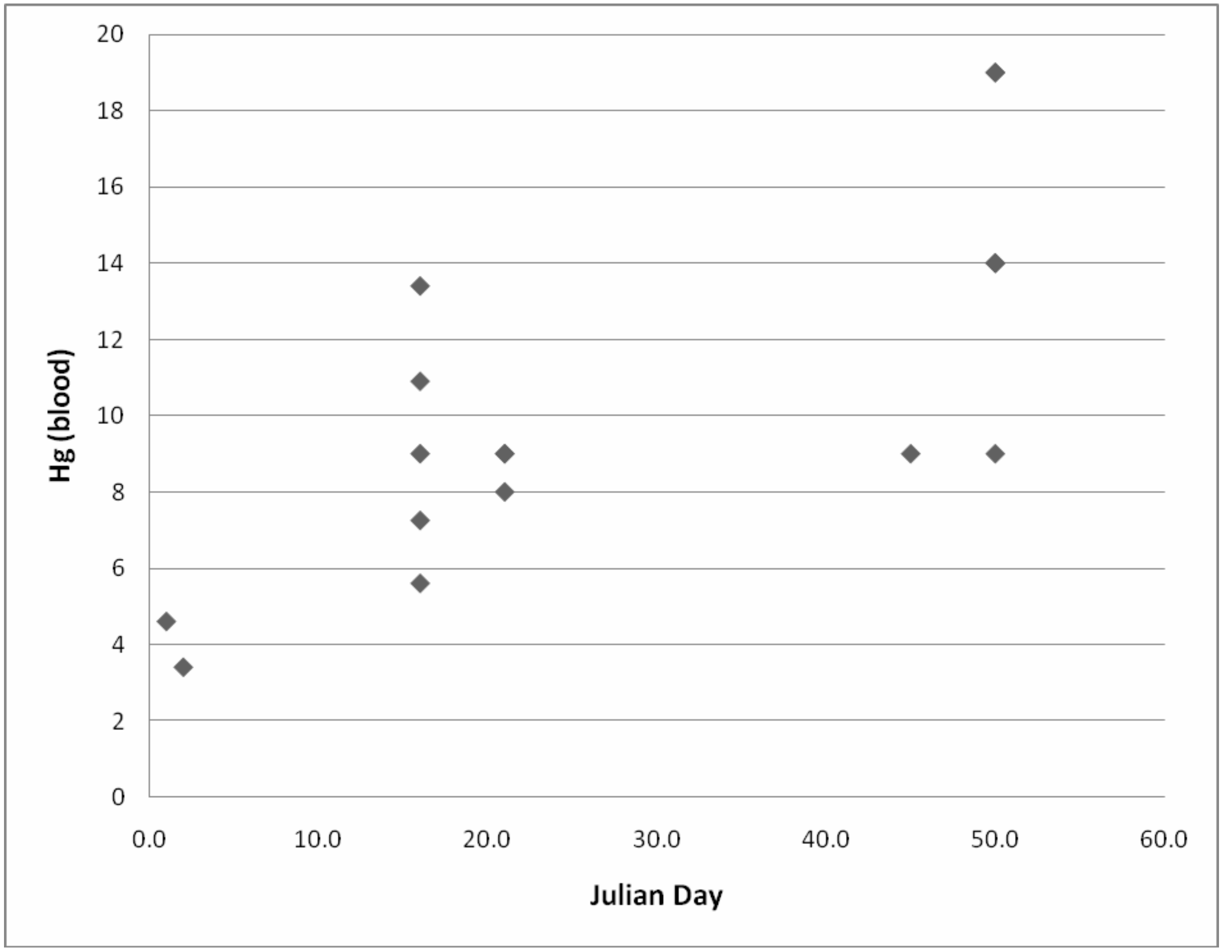


Figure 4. Effect of collection day (Ordinal day 1 is November 29, 2005 while day 50 is January 17, 2006) on mercury concentrations (ug/g dry weight) in the blood of male goldeneyes collected around Fremont Island, Great Salt Lake, Utah.



Appendix 1. Mass (wet weight) and concentrations of selenium and mercury (dry weight basis) of common goldeneyes collected during the winter of 2005-2006 on the Great Salt Lake, Utah.

ID No.	Age	Location	Date	Mass (g)			Se (µg/g)		Hg (µg/g)	
				Body	Liver	Fat	Liver	Blood	Liver	Blood
CG432	Adult	SW Gilbert Bay	3/6/2006	995	27	4.4	25	32	88.5	27.2
CG433	Adult	SW Gilbert Bay	3/6/2006	1074	23	21.1	3.6	1.1	1.6	0.57
CG437	Adult	SW Gilbert Bay	3/22/2006	1023	37	5.1	5.2	4	6.09	3.4
CG438	Adult	SW Gilbert Bay	3/22/2006	1045	36	11.3	25	25	80.7	23
CG439	Adult	SW Gilbert Bay	3/22/2006	1145	28	14.6	34	26	114	29
CG440	Adult	SW Gilbert Bay	3/22/2006	1155	35	5.6	18	12	62.7	27.1
CG445	Adult	SW Gilbert Bay	3/16/2006	1049	28	4.9	23	18	75.4	18.4
CG446	Adult	SW Gilbert Bay	3/16/2006	1122	33	3.8	17	13	50	14
CG450	Juv	SW Gilbert Bay	3/22/2006	992	37	3.7	27	16	94.2	25
CG456	Juv	Gilbert Bay	3/2/2006	921	34	4.0	18	17	57	30
CG469	Adult	SW Gilbert Bay	3/22/2006	1015	43	7.1	10	16	31	16
CG493	Juv	Fremont Island	12/14/2005	1203	32	28.4	6.7	14	9.39	7.25
CG494	Juv	Fremont Island	12/14/2005	1068	26	13.9	14	28	7.6	5.6

CG495	Juv	Fremont Island	12/14/2005	1194	48	16.7	7.6	14	17	13.4
CG497	Juv	Farmington Bay	11/30/2005	1008	39	7.3	8.5	9.7	5.36	3.4
CG513	Juv	Fremont Island	12/14/2005	1018	36	10.1	5.7	7.8	14	10.9
CG514	Juv	Fremont Island	12/14/2005	962	28	5.4	11	13	22	8.95
CG515	Adult	Fremont Island	12/19/2005	1246	39	10.7	7.5	11	11.9	8.14
CG516	Adult	Fremont Island	12/19/2005	1221	37	24.8	9.2	19	12.7	9.24
CG517	Adult	Fremont Island	12/19/2005	1164	32	10.4	14	16	30	9.31
CG523	Juv	Farmington Bay	1/12/2006	1050	34	14.8	7.2	16	10.8	8.98
CG545	Adult	Gilbert Bay	2/16/2006	1017	32	5.8	11	17	23	15
CG555	Adult	Fremont Island	1/17/2006	1238	47	11.5	21	32.2	30	19
CG565	Adult	Fremont Island	1/17/2006	1082	27	6.1	23.4	19	41	9.1
CG566	Adult	Fremont Island	1/17/2006	1038	33	6.1	16	15	48	14
CG587	Juv	Fremont Island	1/17/2006	1050	30	9.8	10	11	23	14
CG594	Juv	Gilbert Bay	12/7/2005	1191	36	19.0	5.5	7.8	11.6	8.5
CG596	Adult	Carrington Bay	2/9/2006	1089	24	9.1	18	22.9	51.4	16
CG600	Adult	Carrington Bay	2/9/2006	1130	22	9.6	17	13	44	13.2
CG601	Adult	Carrington Bay	2/9/2006	1058	26	5.3	20	19	52.1	22.8
CG606	Juv	Fremont Island	11/29/2005	1094	42	9.5	4.4	3.5	5.07	4.6
CG616	Juv	Carrington Bay	2/9/2006	960	28	4.9	20	23	63.9	23.2

CG617	Adult	Carrington Bay	2/9/2006	1159	22	20.7	21.8	22	65	16
CG621	Juv	Carrington Bay	2/9/2006	954	29	5.1	22.1	24	39	15
CG622	Juv	Carrington Bay	2/9/2006	1052	27	6.2	19	14	71.2	19
CG626	Adult	Fremont Island	1/17/2006	1254	36	14.5	24.1	33	39	19
CG627	Adult	Fremont Island	1/17/2006	1142	26	10.3	25.2	26	59.1	14
CG642	Juv	Fremont Island	1/17/2006	1056	36	11.9	15	19	35	15
CG644	Juv	Fremont Island	1/17/2006	1043	23	10.5	15	14	46	15
CG665	Adult	Fremont Island	11/29/2005	1150	27	17.0	5.8	4.3	2.8	2.2